# Achieving 100% renewable generation in Aotearoa/New Zealand

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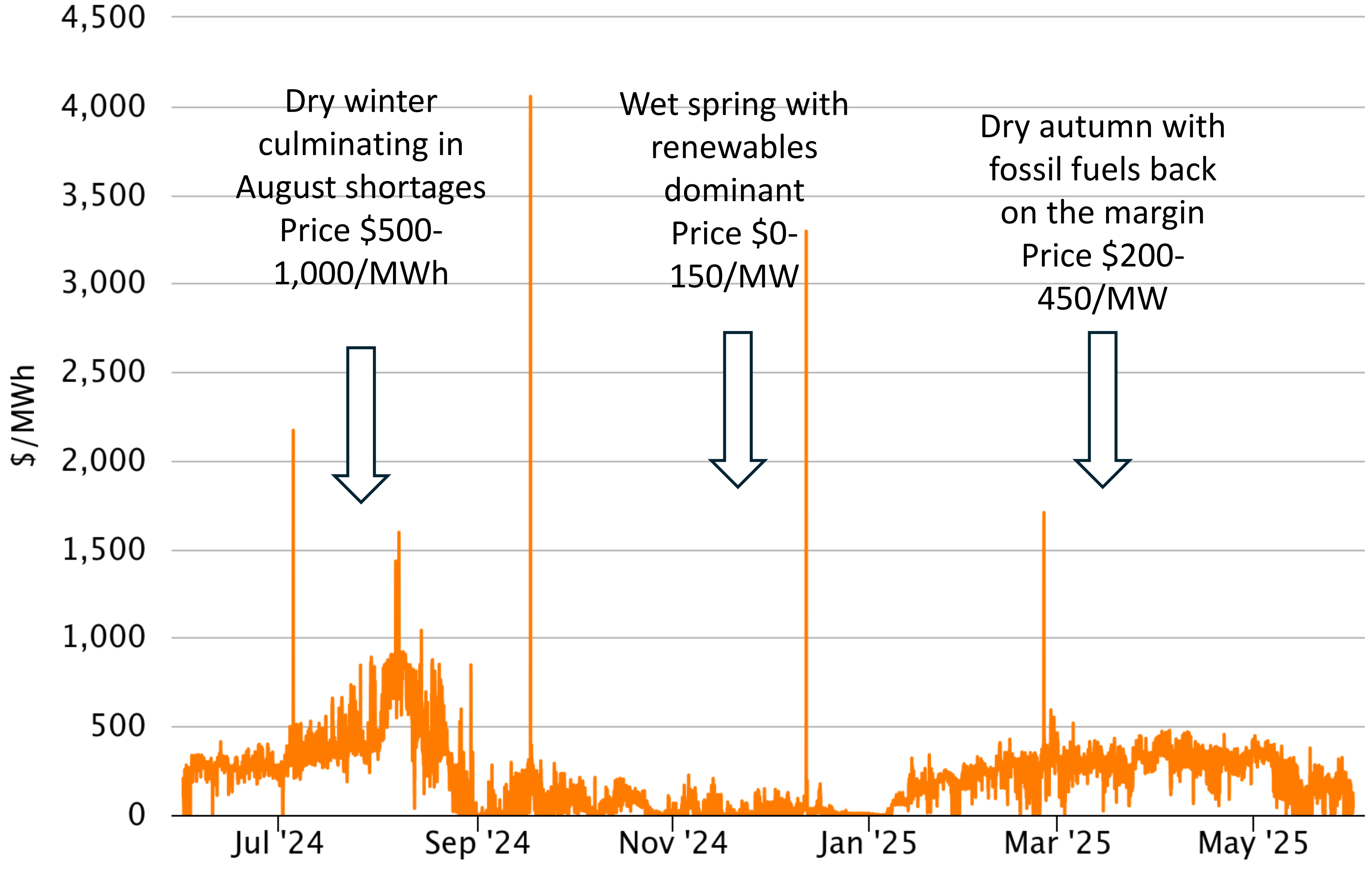
# Central issue with most renewables is intermittency

- The major renewable resources in New Zealand are hydro, geothermal, biomass, wind and solar
- Geothermal and biomass have minimal intermittency
- Hydro is intermittent over long time spans as rainfall interacts with storage lakes of limited capacity
- Wind is intermittent over short time spans as wind intensity and direction change
- Solar is intermittent on a day/night cycle

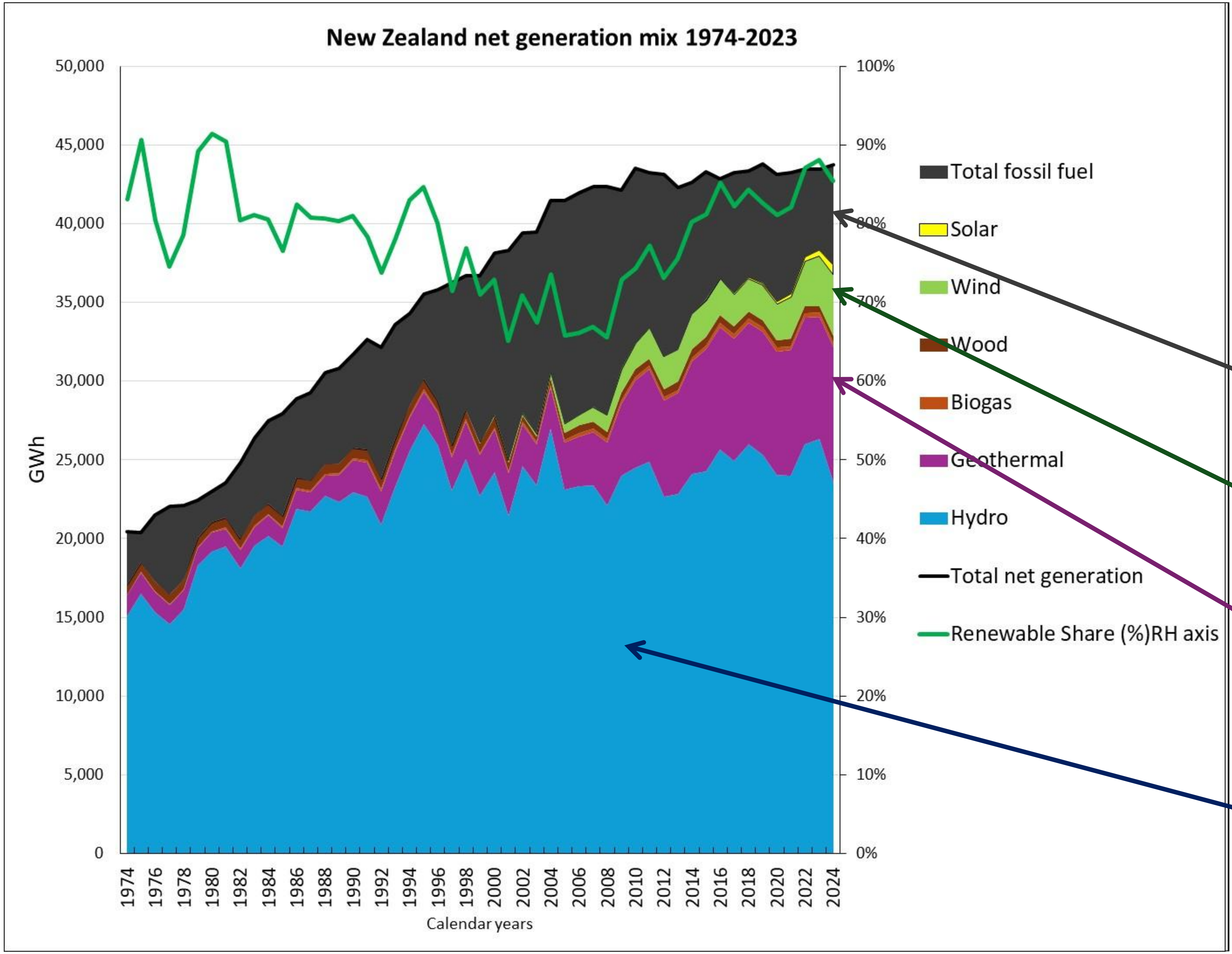
# Results of hydro intermittency: wholesale spot price over the 12 months to June 2025




Note occasional spikes up to $4,000/MW => independent retailers exposed given lack of properly-functioning hedge market

# In a diversified portfolio, these various sorts of intermittency are overlaid on one another

- At some times they will balance each other out
- At other times all intermittency cycles can coincide, producing big upward and downward spikes in total available supply
- Our focus is on modelling a portfolio of hydro, geothermal, biomass, wind and solar to meet a 100% renewable generation target at least cost
- One crucial fact is that the hydro system has storage as well as energy-flow built in => can be used as backstop to other renewables




Total generation is nearly flat since 2012.

Renewables share in 2024 was the same as fifty years ago – just below 90%

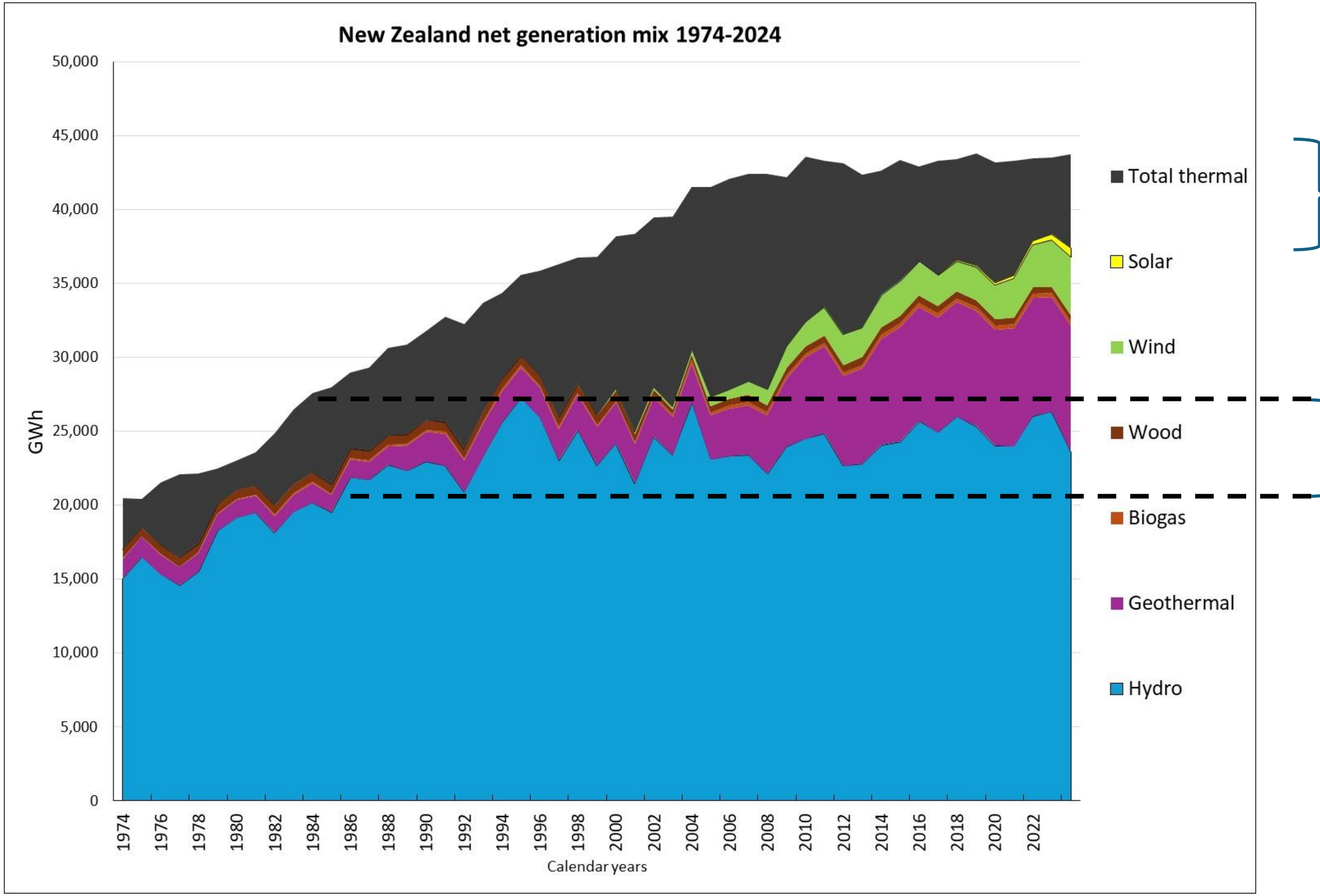
Coal gas and oil stay stubbornly parked on the margin of supply

Wind is growing but solar has lagged and biomass is minimal

Geothermal has been a big mover since 2000

Hydro development was complete by 1990 => this is now a legacy asset

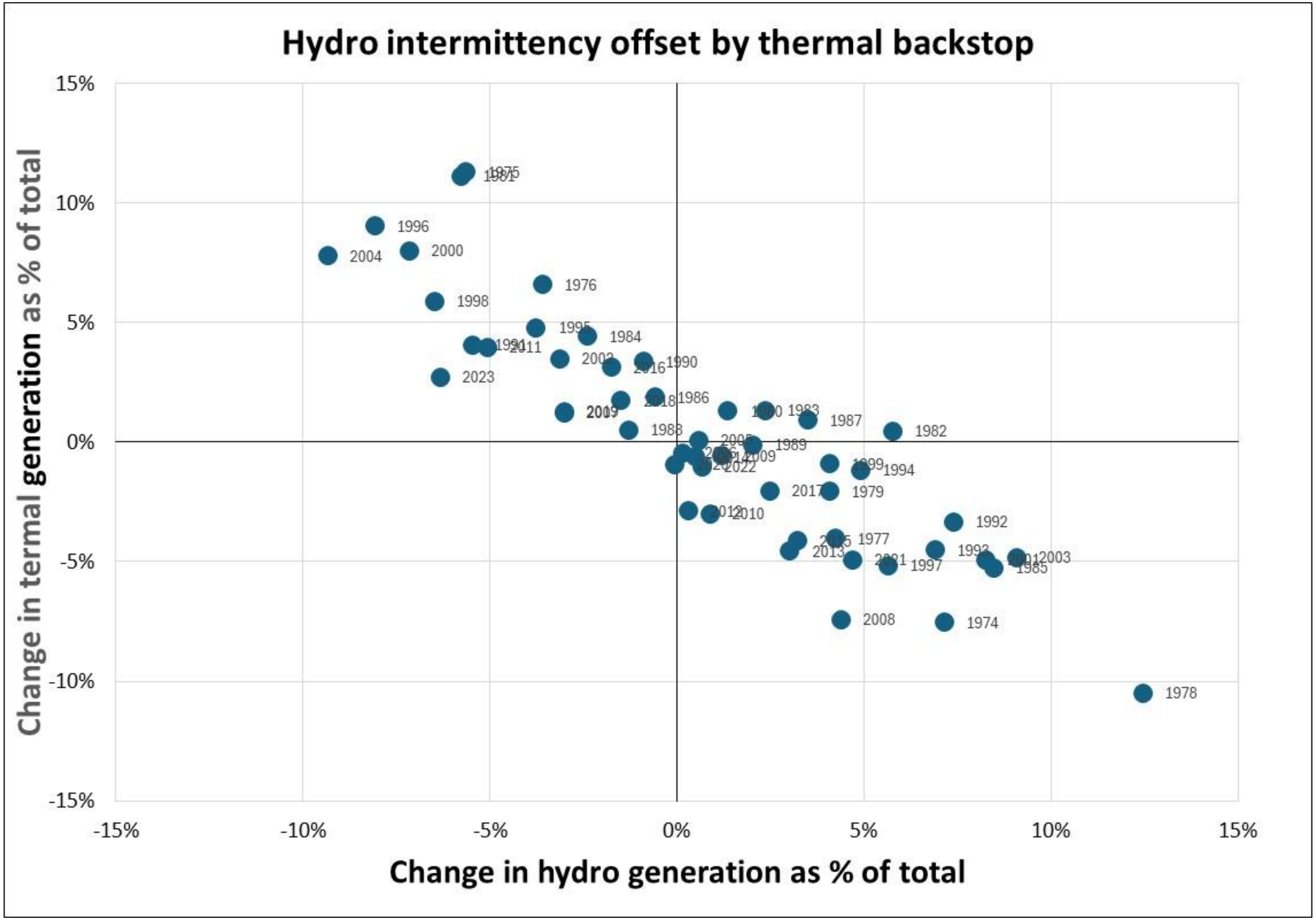
# Dry years or seasons are the big issue for hydro intermittency, currently solved with fossil fuels




Fossil fuels sit on the margin of supply and provide the backstop for hydro over dry years or seasons

Legacy hydro output ranges between 20,000GWh and 28,000 GWh depending on the weather

That’s a range of nearly 20% of total generation – intermittency on a seasonal and/or annual scale



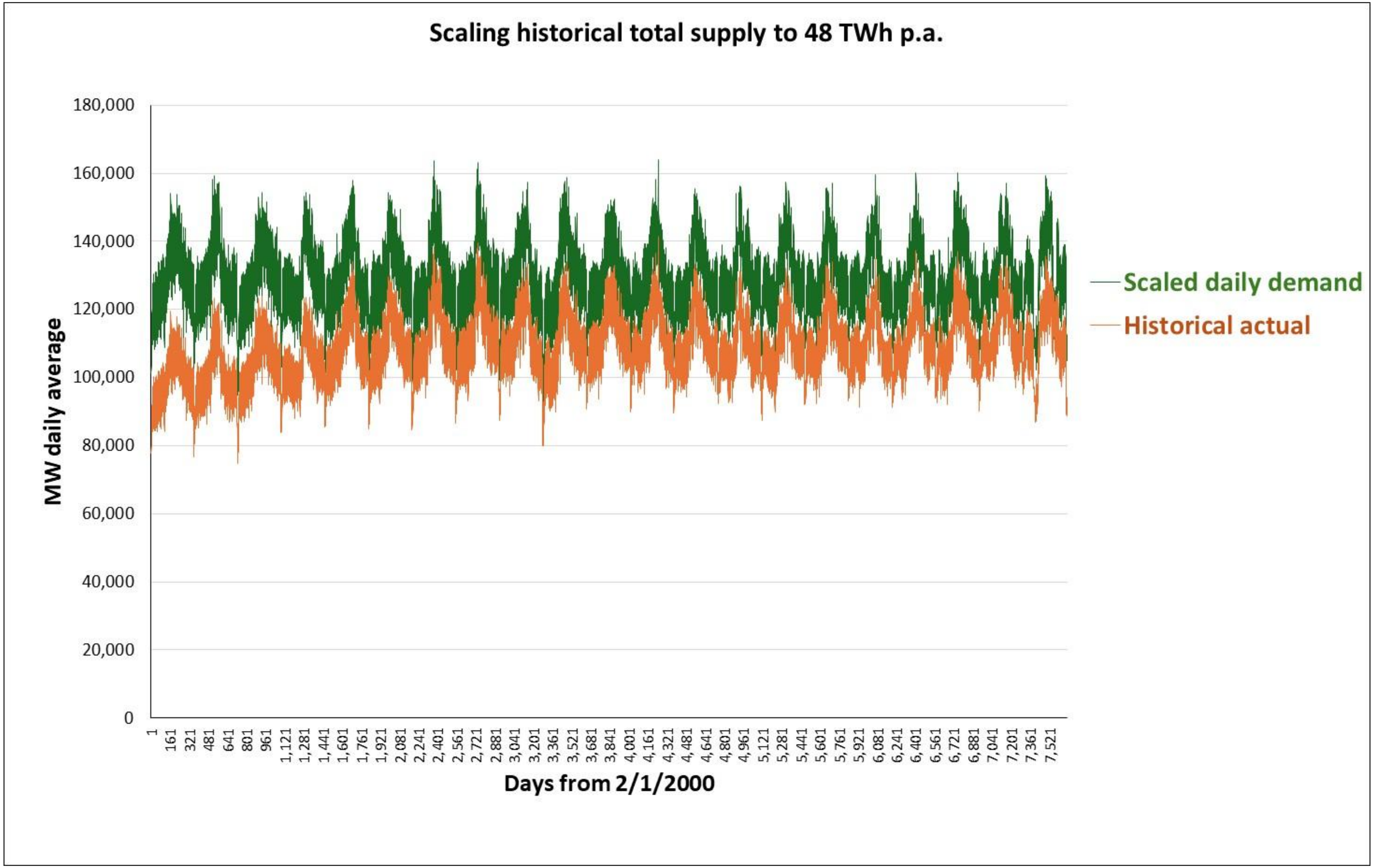
Hydro intermittency offset by thermal backstop
Change in termal generation as % of total
Change in hydro generation as % of total
15%
10%
5%
0%
-5%
-10%
-15%
-15%
-10%
-5%
0%
5%
10%
15%
1996
2004
2000
1976
1998
1984
2023
1990
1986
1987
1982
1994
1979
1992
1977
1997
2003
2008
1974
1978

# The modelling exercise

- Install enough wind and solar capacity to meet projected demand day by day with
  - 100% renewable supply (fossil fuels driven off the margin)
  - Reliability: no day of outage even in dry years
  - Cost minimising: seek an optimal combination of
    - Capital cost of new renewable capacity
    - Minimal spill (foregone opportunity value) of water, wind and solar potential generation
- Simplifying assumption for this stage of modelling: within-day mis-matches between supply and demand are covered by hydro within-day flexibility, plus batteries.

# Model set-up

- Set annual demand at 48 TWh (the forecast for 2035).
- Assemble actual historical New Zealand data on a daily basis 2000-2020 for
    - Daily demand: scale the historic daily series up to sum to 48TWh per year
    - Hydrology, measured as actual daily output from the legacy hydro system
    - Solar and wind capacity factors for each day, derived from hour-by-hour solar capacity factors over a set of New Zealand sites from https://renewables.ninja/
    - Geothermal baseload output: actual historical output scaled up to an assumed 1,700MW of capacity
- The resulting spreadsheet has 7,670 rows, one for each day 2000-2020
- Now build up a generation stack sufficient to have supplied 48TWh p.a. of 100% renewable electricity on every day over that two-decade model period

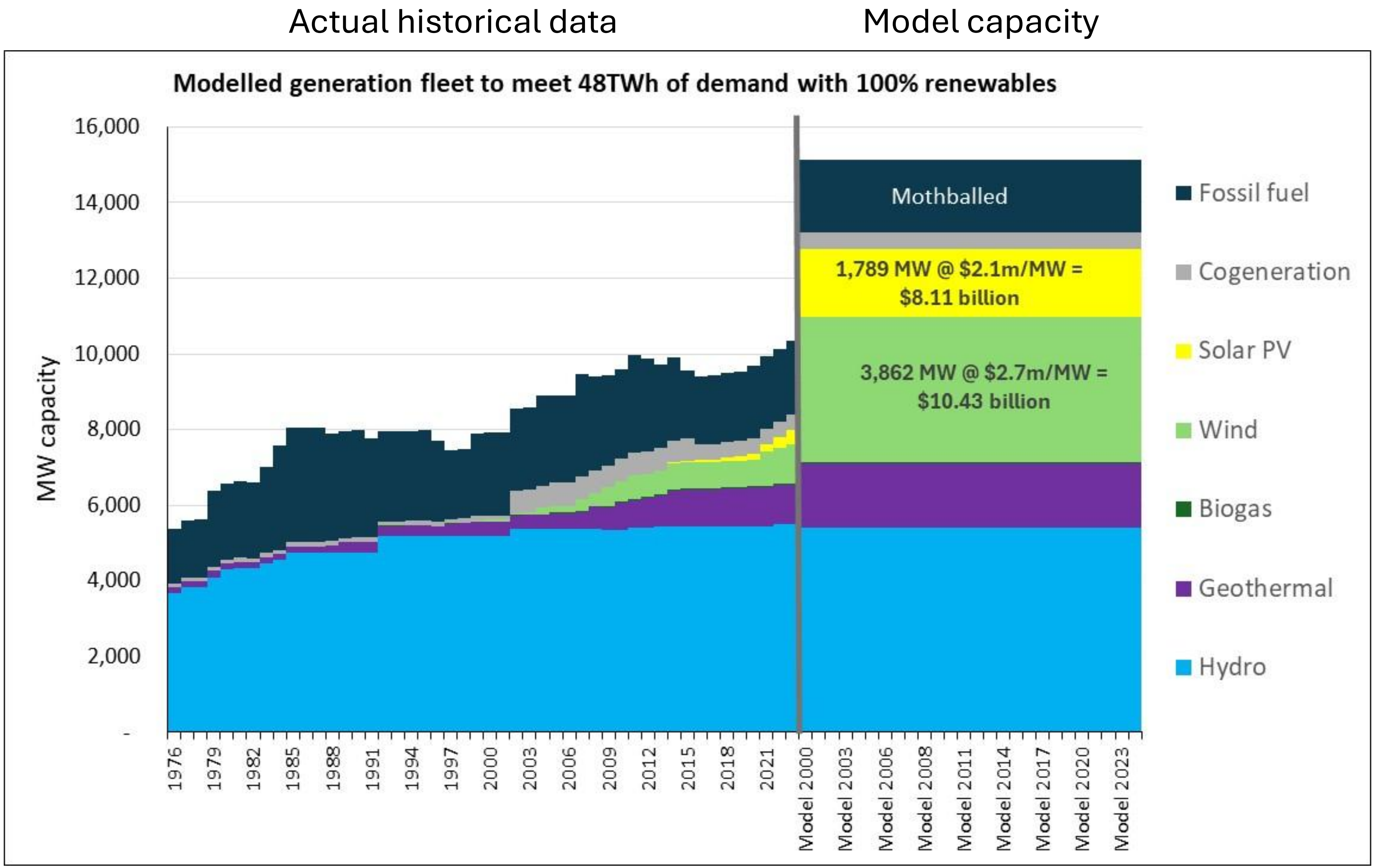


Scaling historical total supply to 48 TWh p.a.
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
MW daily average
Days from 2/1/2000
Scaled daily demand
Historical actual

# Building the generation-fleet stack

- Start with existing hydro capacity of 5,400MW, available subject to two constraints:
  - Hydro generation may not drop below 800MW, in order to sustain minimum flow levels on the rivers
  - Water storage in the lakes at the heads of the rivers has a maximum of 4,500GWh worth of water. If lakes fill beyond this the water is spilled to waste.
  - When the lake levels rise above a trigger point, initially set at 3,600GWh, all hydro capacity must be fully utilised to slow down accumulation of water in the lakes
- Assume geothermal capacity will have increased to 1,700 MW by 2035 in line with conservative projections for 2035 (hence this is part of the business-as-usual base case)
- Asssume biomass capacity remains unchanged with daily output at historical levels
- Now add tranches of wind capacity and tranches of solar, operating under the capacity factors from https://renewables.ninja/, until the 100% target is achieved

# Example of a model solution for installed capacity



# Hydro re-dispatch

- At present the legacy hydro capacity is operated on a profit maximising (and rent-seeking) basis by corporate owners
- This means its dispatch, if done on the basis of actual historical daily output, is not coordinated with the new wind and solar intermittent supply
- The model therefore re-dispatches hydro capacity, subject to the constraints of rainfall, lake levels and river minimum flows, to counterbalance highs and lows in wind and solar output
- Wind, solar and hydro all bid into the wholesale pool at zero, but our model's redispatch procedure gives wind and solar priority, because hydro is the one that has variable storage built in
- So we use the hydro system as a  battery backstop to wind and solar

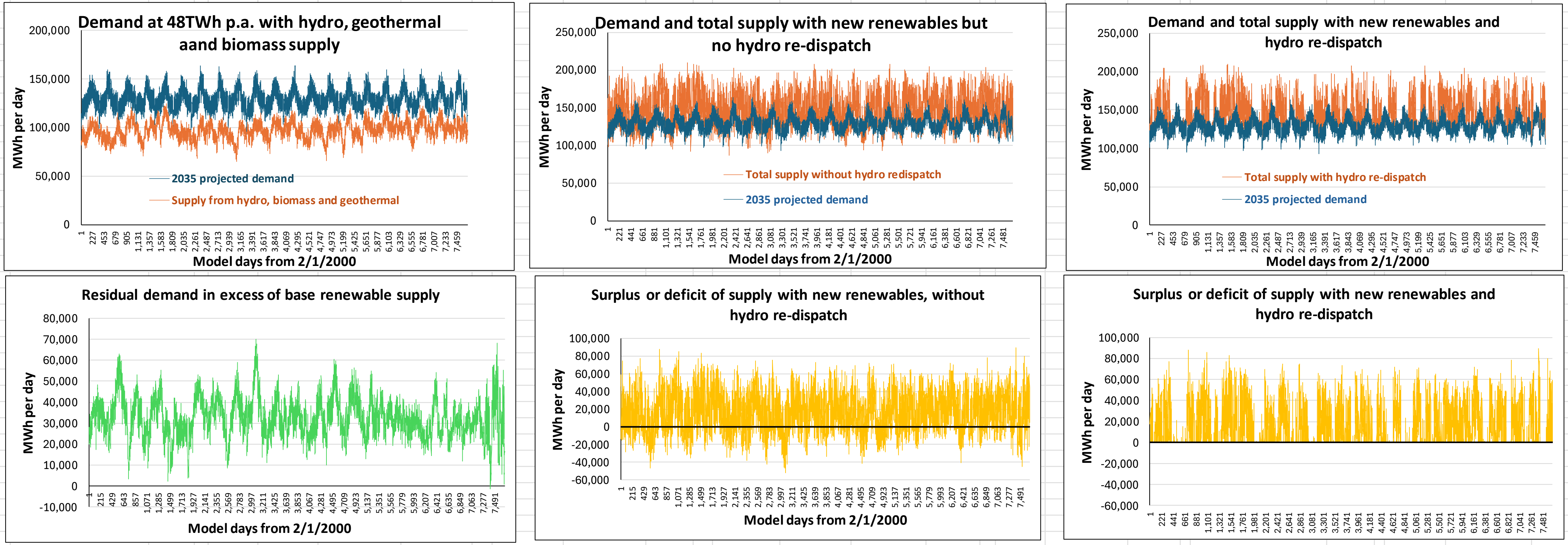
# Sample run of the model

## Model inputs

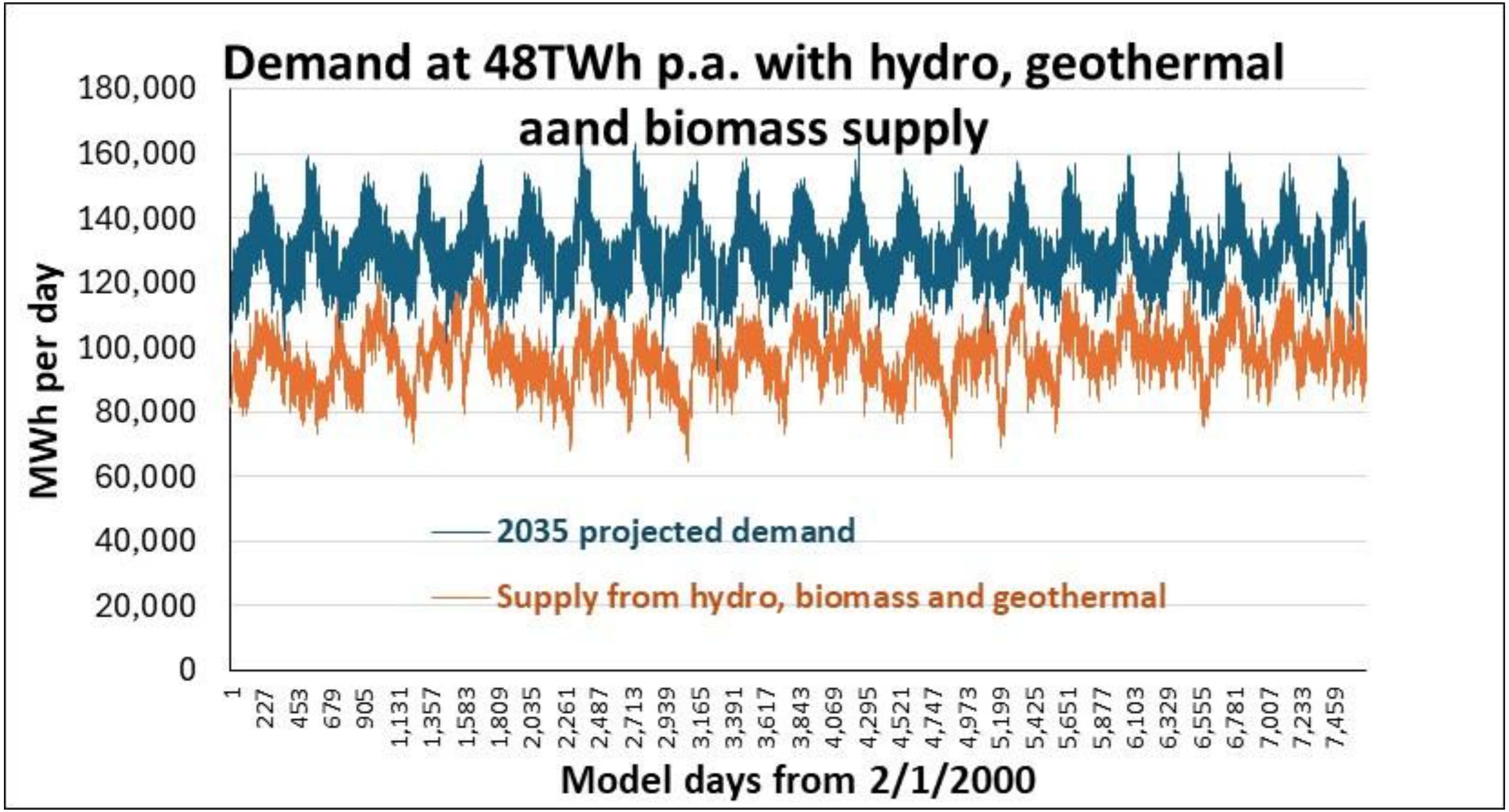
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand TWh pa | 48 | Lake level maximum GWh | 4,500 | Lake level minimum | 0 | Trigger for hydro limit GWh | 3,600 | Cost of spill $/MWh | 40 | Wind capacity MW | 3,872 | Solar capacity MW | 1,789 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Capital cost of wind capacity | 2.70 | Capital cost of solar capacity $m per MW | 1.75 | Existing wind capacity | 1,046 | Existing solar capacity | 372 |

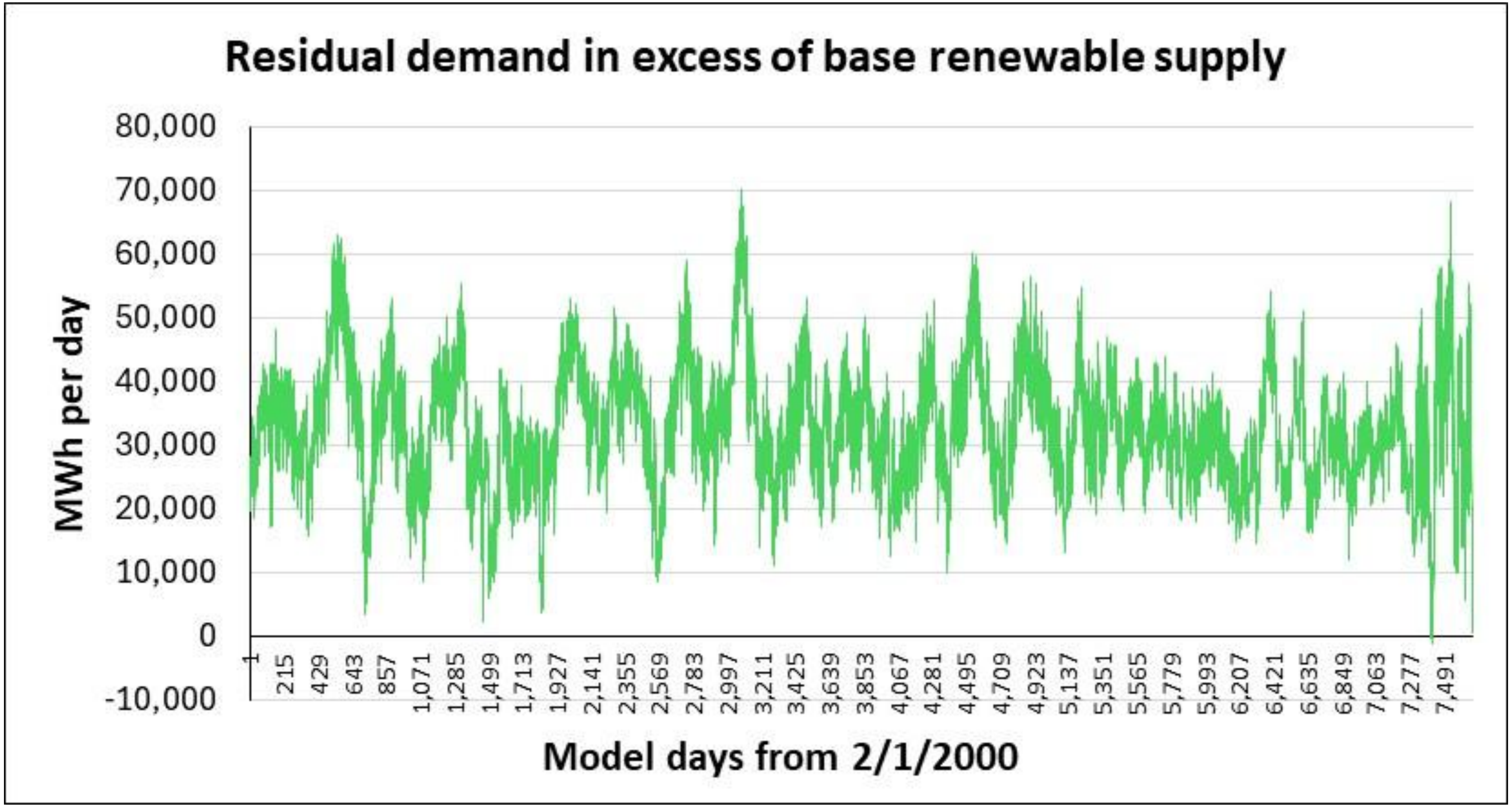
| Number of outages (days) | Hydro spill GWh | Wind & solar spill MWh | | Total spill MWh | Spill cost $million pa | Wind capex $m | Solar capex $m | Total capex |
|---|---|---|---|---|---|---|---|---|
| 0 | 1,075 | 5,311 | 35% | 6,386 | 255 | 7,630.2 | 2,480 | 10,110 |



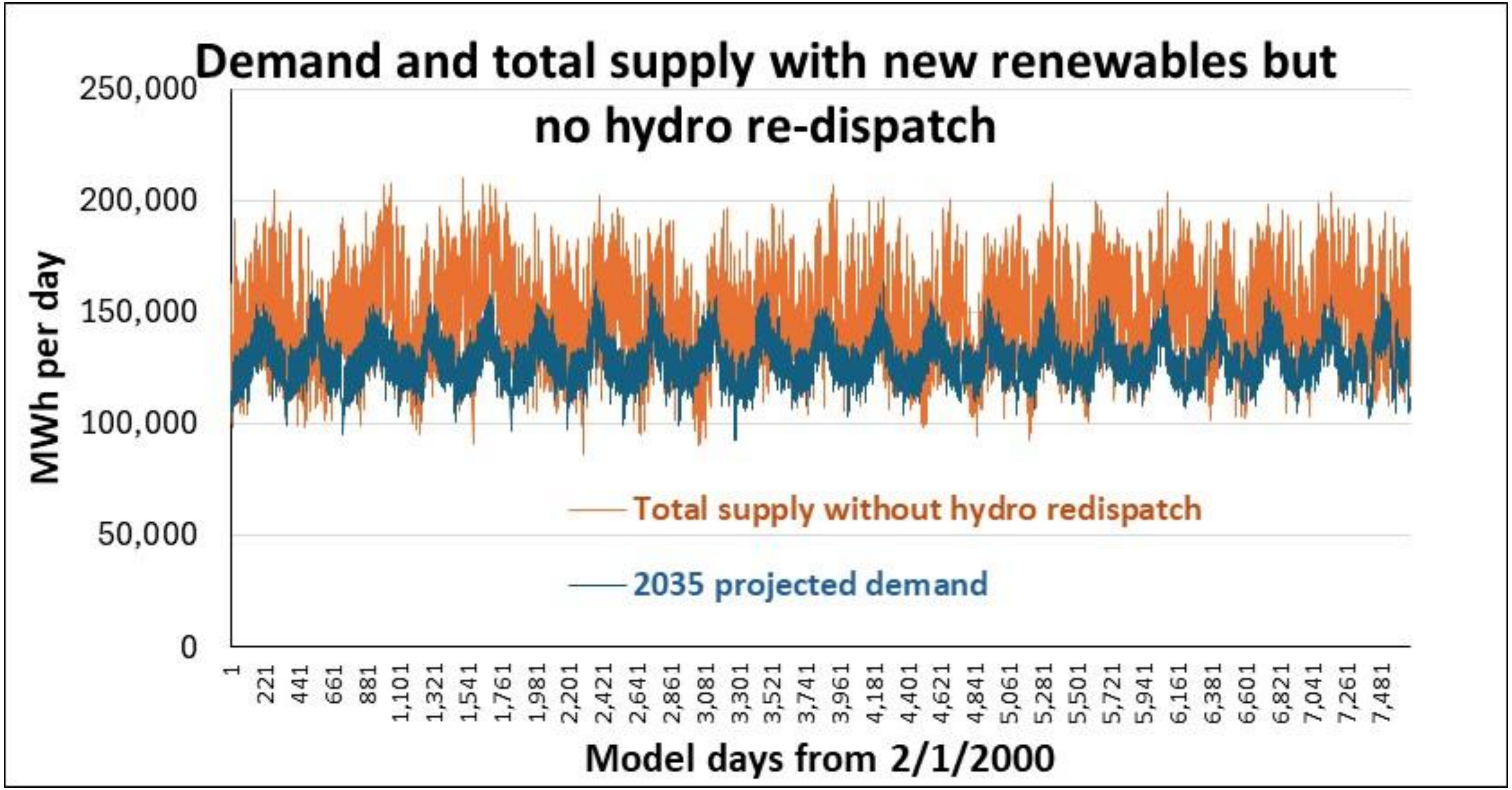
# Taking those step by step: start with



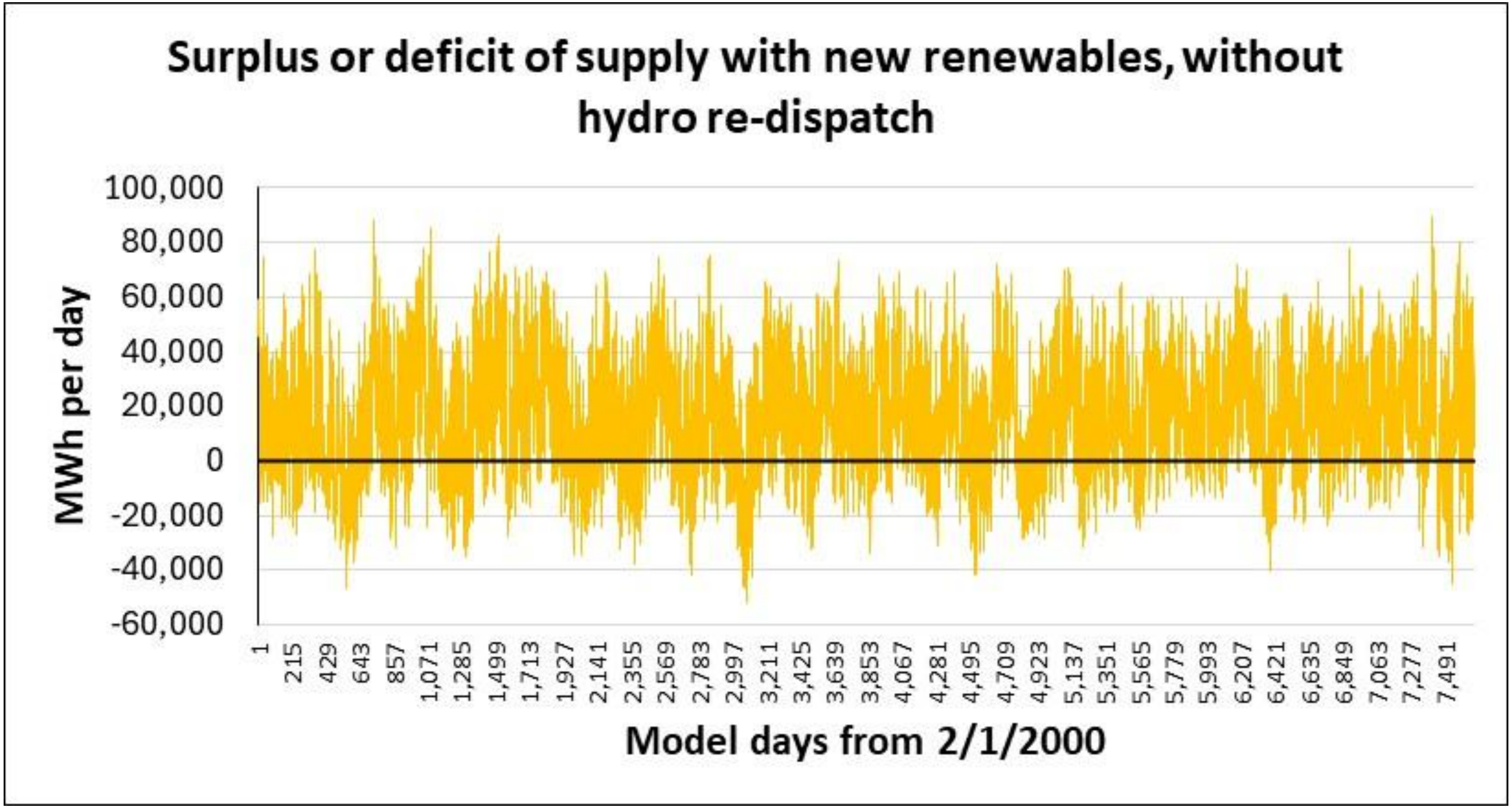
# That leaves residual demand to be met by new renewables:



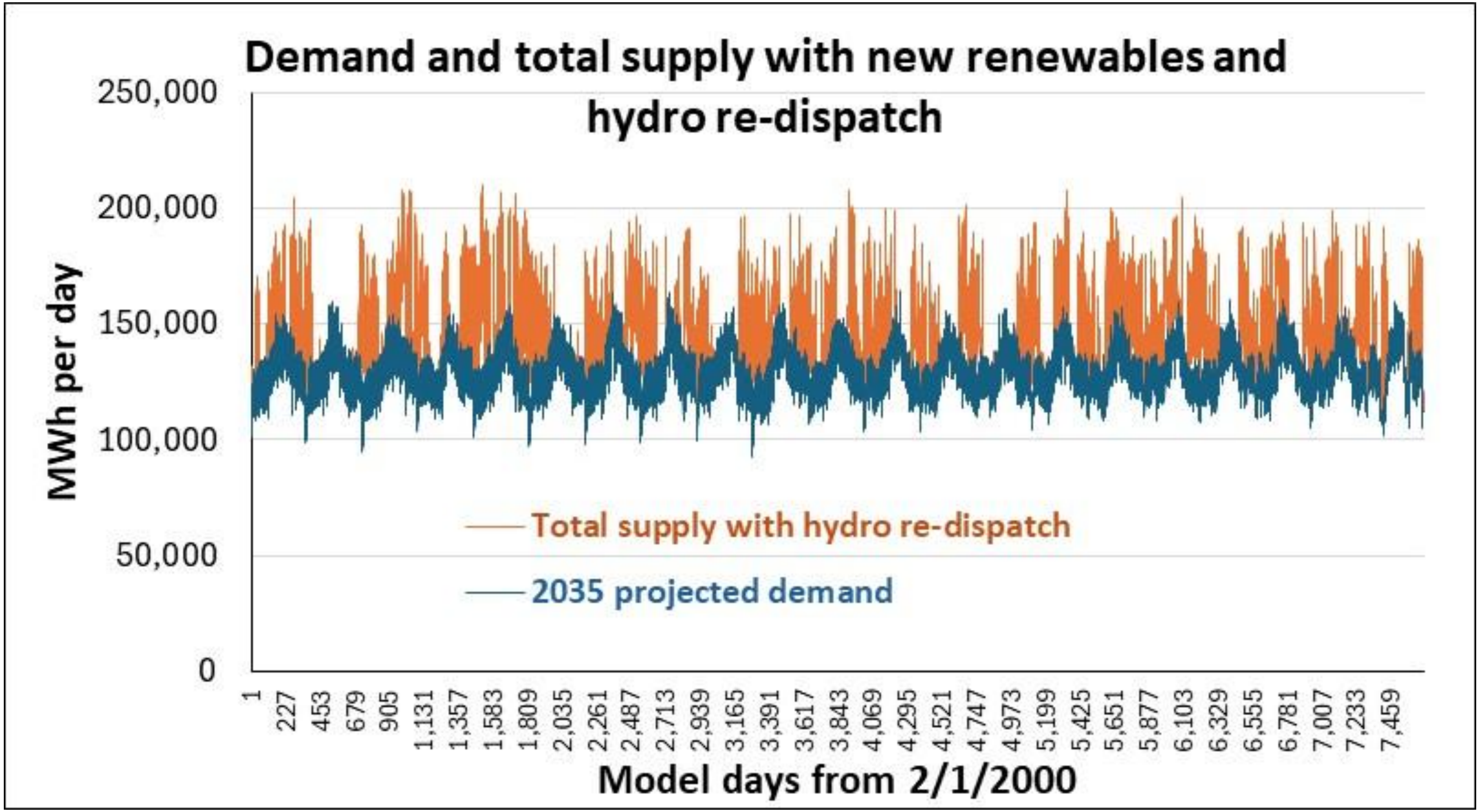
# Next step: add wind and solar to the supply:



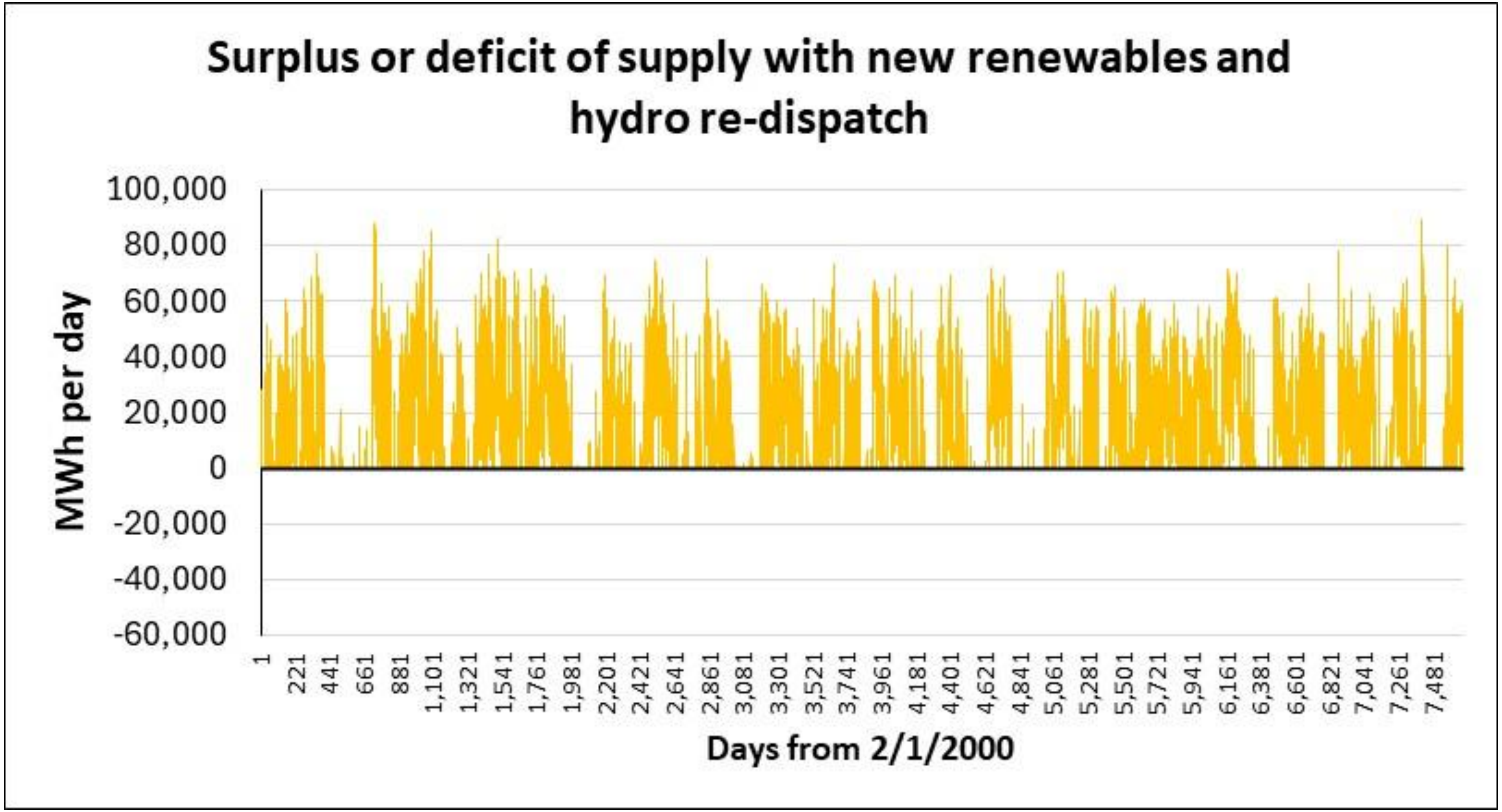
There are still numerous periods when demand exceeds supply:



# Now we re-dispatch the hydro system to provide a battery-style backstop to wind and solar:



# That brings supply into balance with the day-by-day pattern of demand:



# The dashboard shows the detailed results

## Model inputs

| | |
|---|---|
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| Lake level maximum GWh | 4,500 |
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| Capital cost of wind capacity | 2.70 |
| Capital cost of solar capacity $m per MW | 2.10 |
| Existing wind capacity | 1,046 |
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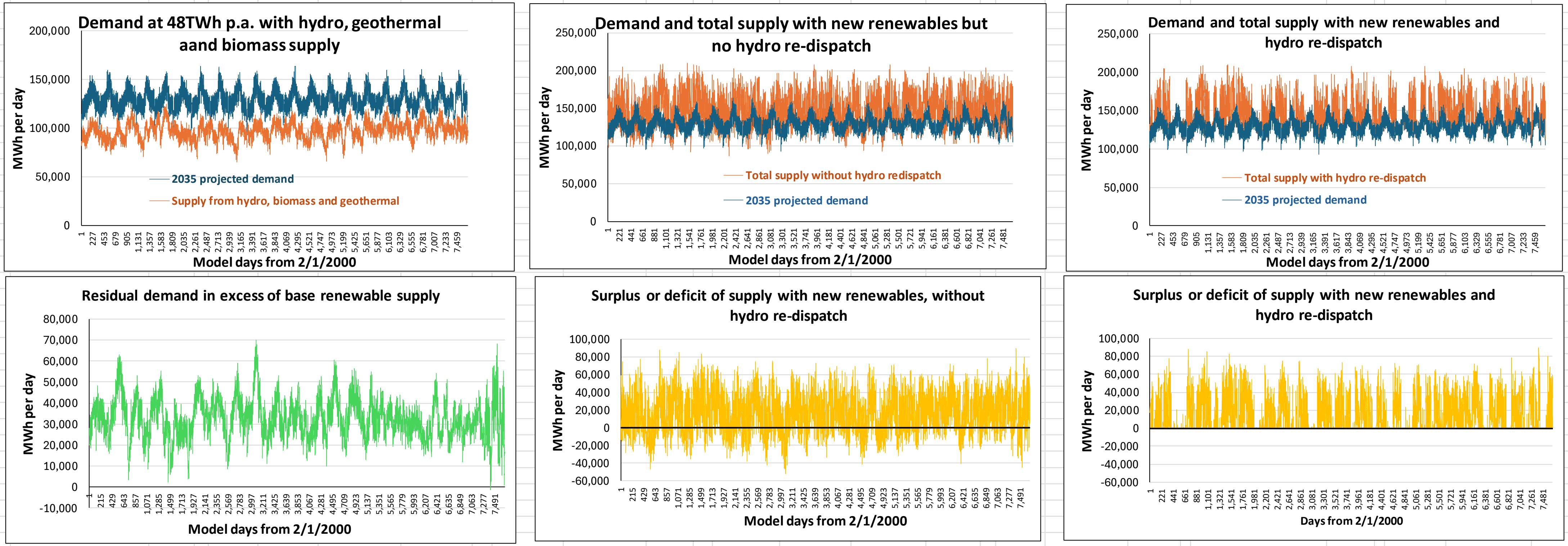
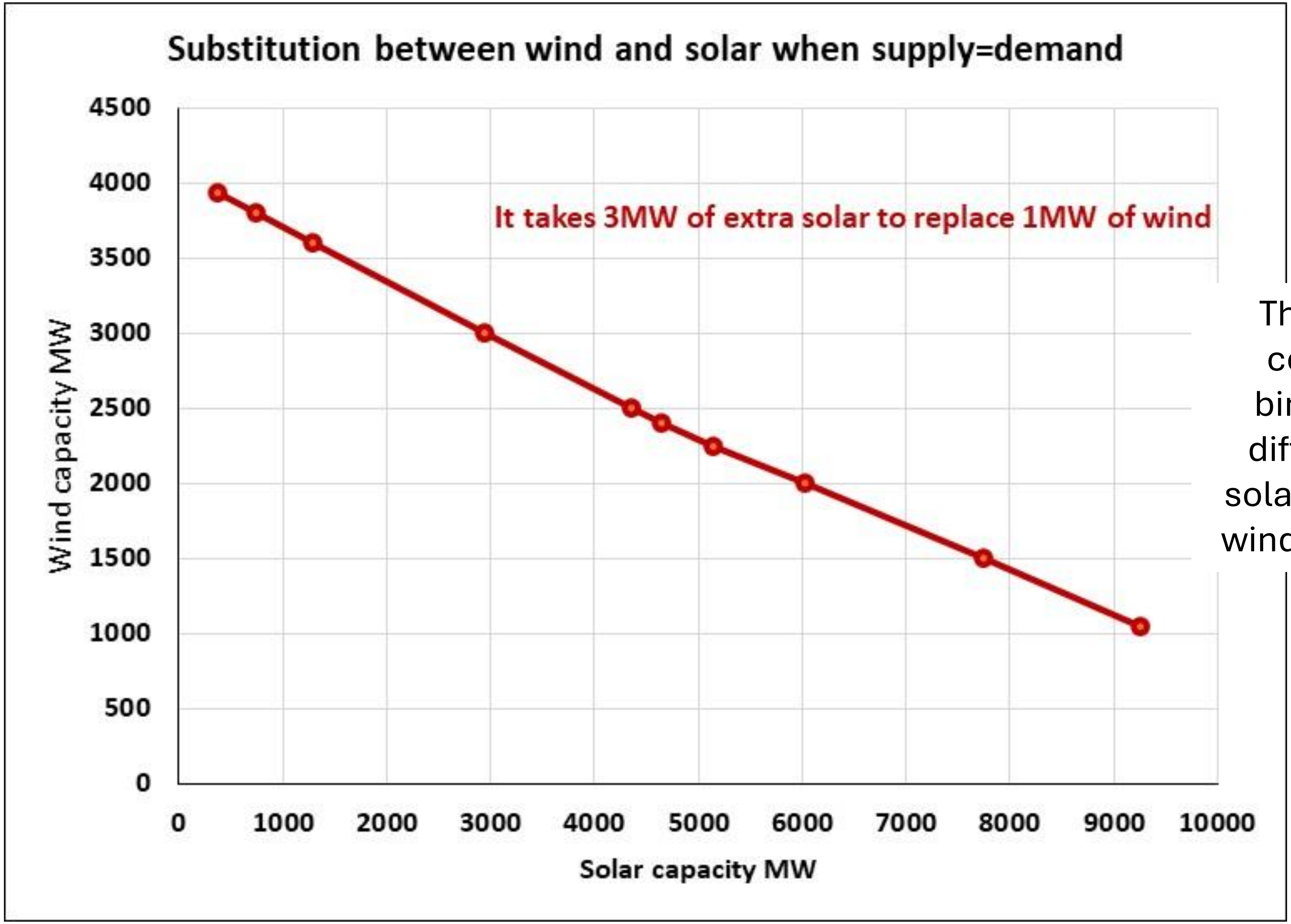
## Model outputs

| Number of outages (days) | Hydro spill GWh | Wind & solar spill MWh | | Total spill MWh | Spill cost $million pa | Wind capex $m | Solar capex $m | Total capex |
|---|---|---|---|---|---|---|---|---|
| 0 | 1,075 | 5,311 | 35% | 6,386 | 255 | 7,630.2 | 2,976 | 10,606 |

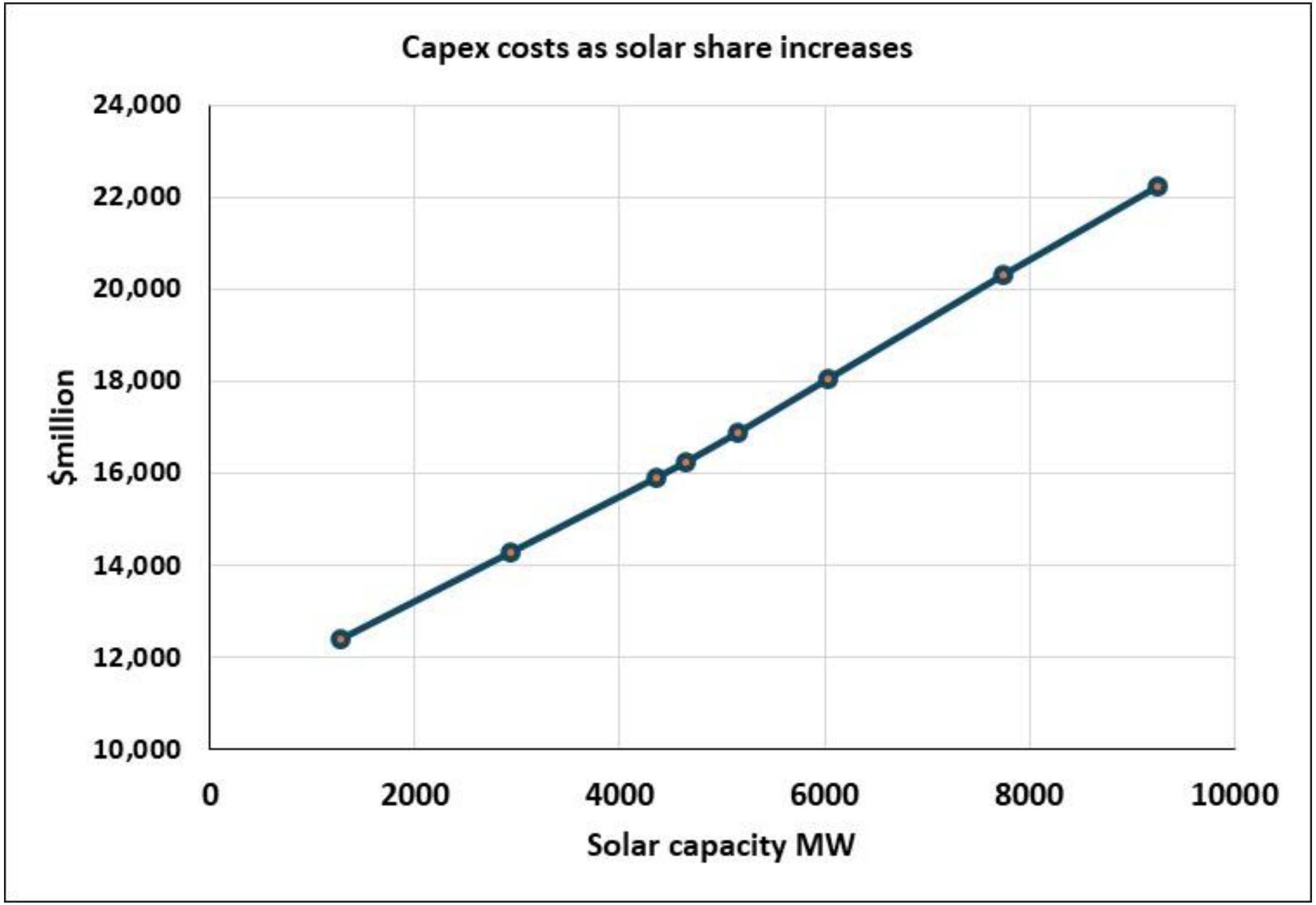


# Some other results

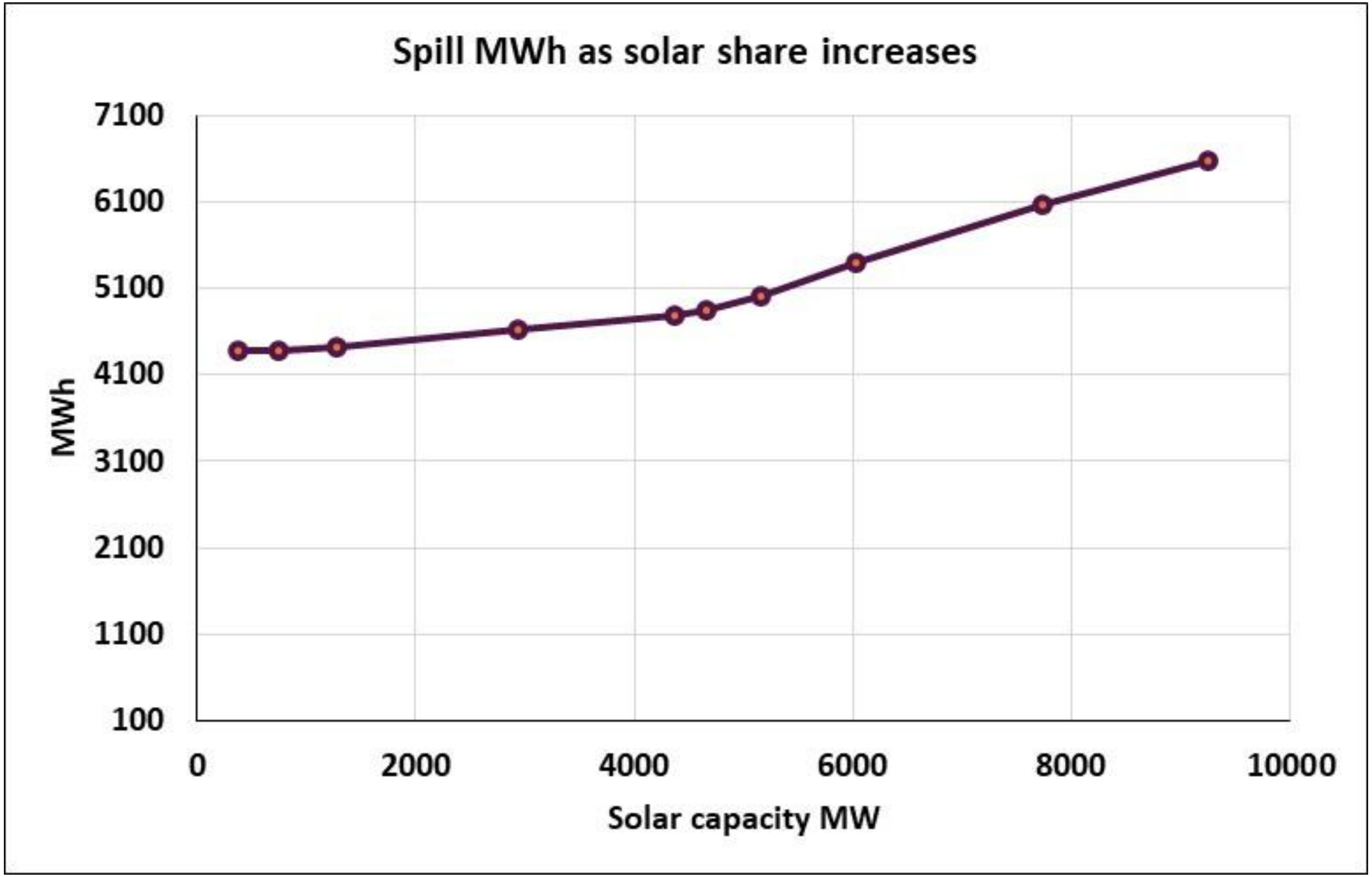



The isoquant is actually slightly concave – although there is no binding resource constraint, the different intermittency pattern of solar makes it less substitutable for wind as installed wind capacity falls

# Capital cost of installing the new renewable capacity increases as the solar proportion of the new fleet rises

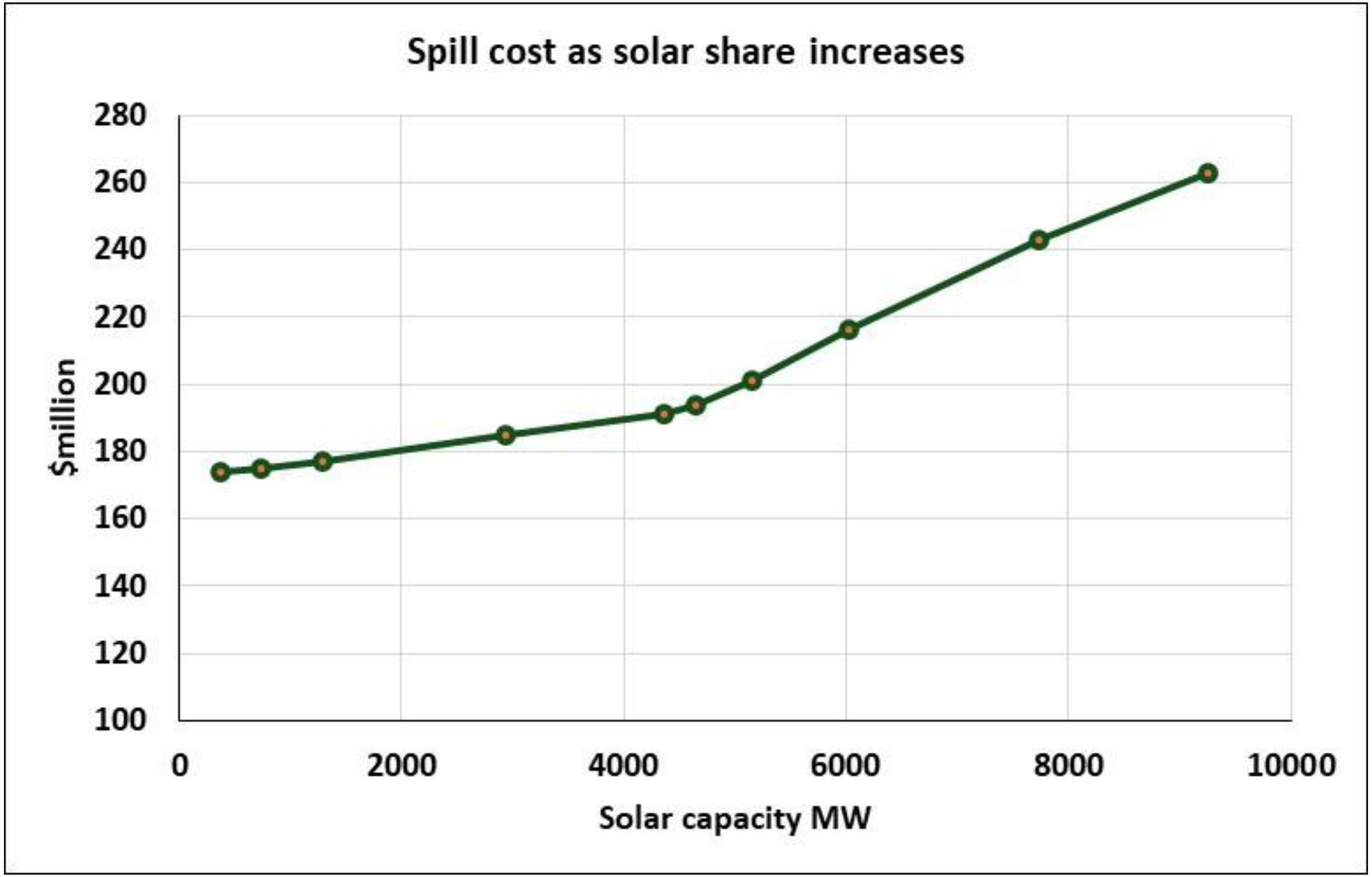


# The amount of spill rises with the solar proportion




Poletti and Bertram 100% renewable generation in New Zealand

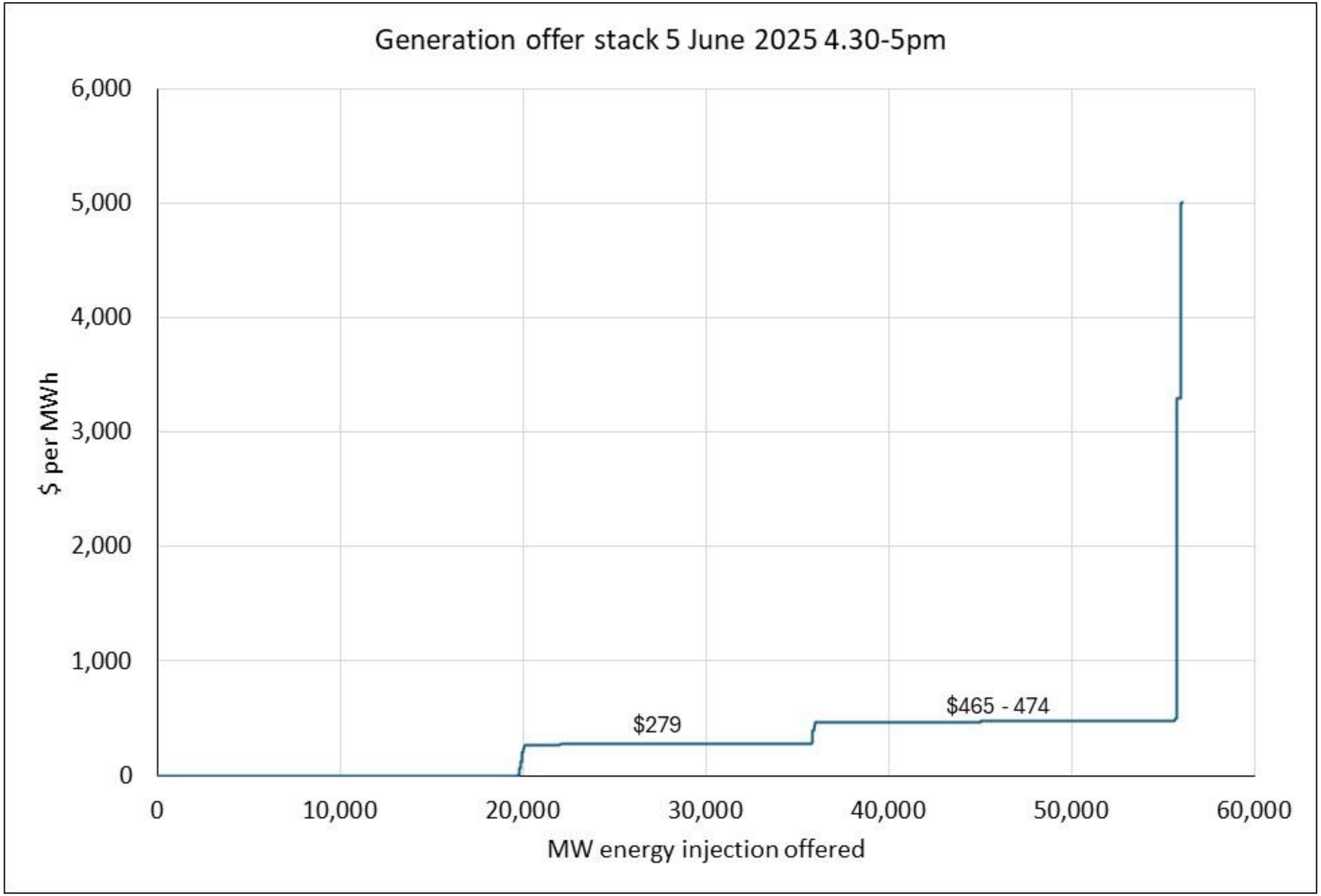
# The costs of spill equally go up as the solar share rises



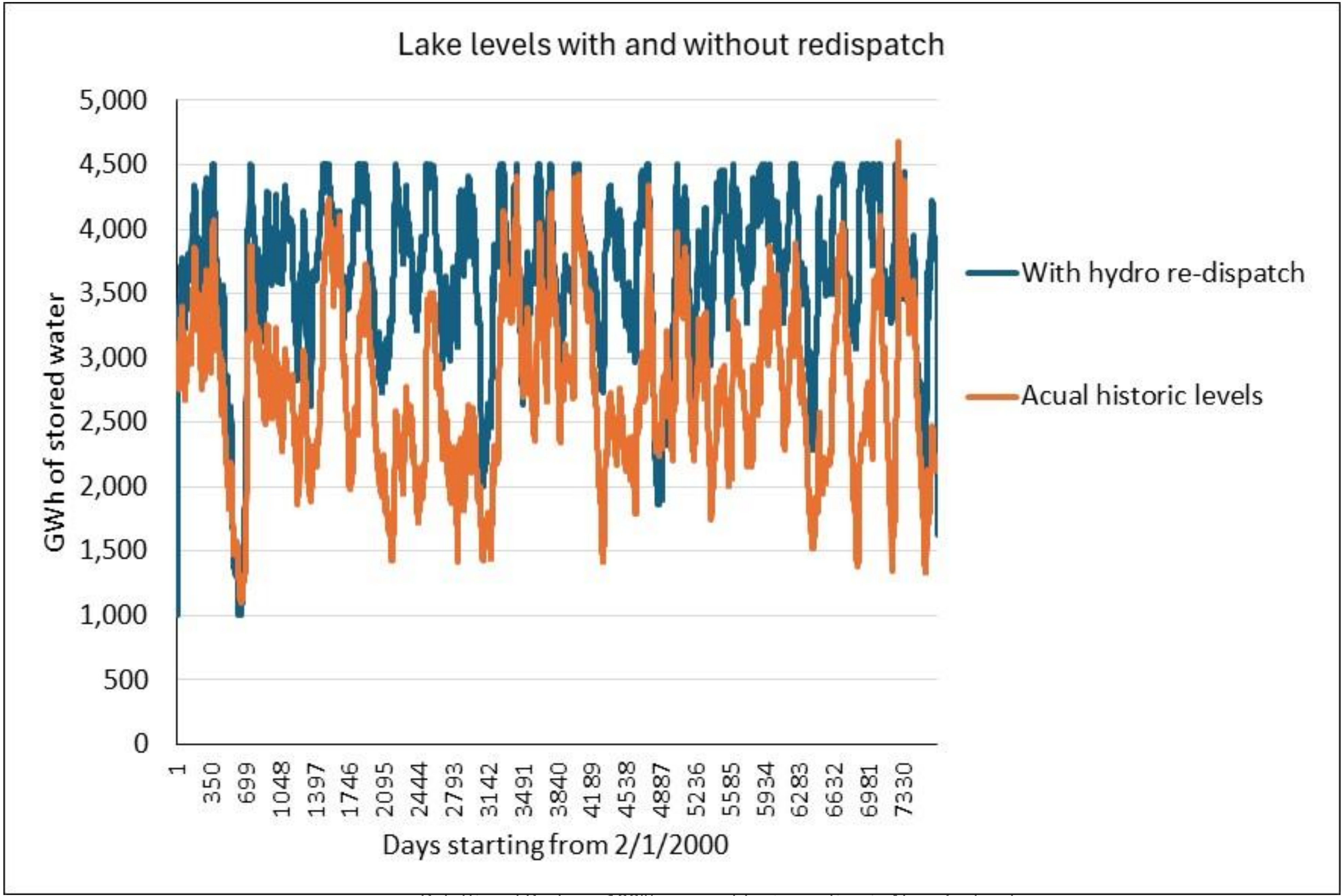
## These results would seem to point strongly towards large-scale wind deployment as the key

- But there are other factors that point to keeping solar in the mix
  - Diversity gives greater resilience
  - Solar is suited to more small- and medium-scale independent projects including rooftops in cities and towns
- The model can now be used with varying prices and constraints to explore the detail of achieving 100% renewable supply in New Zealand
- The feasibility is established
- The cost remains an issue: not less than $12 billion in the runs shown today with wind at the assumed $2.7 million/MW. But costs are falling……

# Extra slides



Generation offer stack 5 June 2025 4.30-5pm
6,000
5,000
4,000
3,000
2,000
1,000
0
$ per MWh
$279
$465 - 474
0
10,000
20,000
30,000
40,000
50,000
60,000
MW energy injection offered


Lake levels with and without redispatch
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
GWh of stored water
1
350
699
1048
1397
1746
2095
2444
2793
3142
3491
3840
4189
4538
4887
5236
5585
5934
6283
6632
6981
7330
Days starting from 2/1/2000
With hydro re-dispatch
Acual historic levels